Pacific Science (1975), Vol. 29, No. 1, p. 15–18
Printed in Great Britain

A Comparison of Effects of Elevated Temperature versus Temperature Fluctuations on Reef Corals at Kahe Point, Oahu[1]

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ABSTRACT: Bottom temperature and the condition of live corals in the vicinity of the discharge plume from the Hawaiian Electric Company Kahe Generating Station, Oahu, Hawaii, were monitored August–December 1973. Mortality to *Pocillopora meandrina*, the most thermally sensitive species of the area, was no greater under conditions of maximum thermal enrichment near the living reef fringe in the discharge area (1–2 m depth) than in an area (4–5 m depth) more distant from the discharge. Sublethal coral damage was more pronounced near the discharge, but was mostly limited to loss of zooxanthellar pigment which was restored following yearly ambient temperature maxima. Although bottom temperatures in the discharge area continually varied 3°–4° C within minute periods during every low tide, live corals seldom encountered temperatures exceeding 31° C. The limited damage that occurred to live corals indicates that upper absolute temperatures are more critical in producing coral damage than are short-term temperature shocks near upper lethal limits.

THE RESULTS of a 2-year study of the effects of the Hawaiian Electric Company (HECO) Kahe Generating Station, Oahu, Hawaii (Jokiel and Coles 1974), indicated the increased temperature of thermal effluent to be the critical factor damaging and killing hermatypic corals on the shallow reef. However, a question remained from this study as to the relative importance of the effects of the absolute upper limits of temperature in producing mortality versus stresses imposed by rapid fluctuations in temperature near upper limits of tolerance. An additional question remained as to whether coral damage had yet come to equilibrium following an increase of station operation from three to four generating units during 1972.

Additional studies of thermal effects were continued as part of a HECO sponsored monitoring program during the summer and fall months of 1973, when all four Kahe generating units were in full operation.

The assistance of Dr. J. C. McCain, J. M. Peck, S. Kaolulo, and S. Shupe is gratefully acknowledged.

METHODS

Five transects, each 20 m long, were established on 26 July 1973 on the shallow reef in the discharge area. The shoreward terminus of the northernmost transect (transect 1) coincided with the seaward terminus of the discharge transect of the Jokiel and Coles (1974) study, ca. 160 m from the discharge. The remaining four shallow transects were similarly distant from the discharge, with the shoreward end of all five transects terminating where living, normally pigmented coral could be found (Figure 1). Depth along these transects ranged from 1–2 m (MLLW). An additional 20-m transect (transect 6) was located ca. 150 m farther seaward at 4.5 m depth.

Pocillopora meandrina Dana is the most thermal-sensitive coral occurring in the Kahe area (Jokiel and Coles 1974). Therefore, all *P. meandrina* heads 15 cm or more in diameter growing 0.5 m to either side of each transect were tagged with plastic coated electrical wire. Tagged specimens were counted and observed weekly on transects 1–5 through the month of August and approximately biweekly thereafter through the end of October. Observations on transect 6 extended the same period of time but were more intermittent.

[1] Coral Reef Management and Research contribution no. 20. Manuscript received 8 February 1974.

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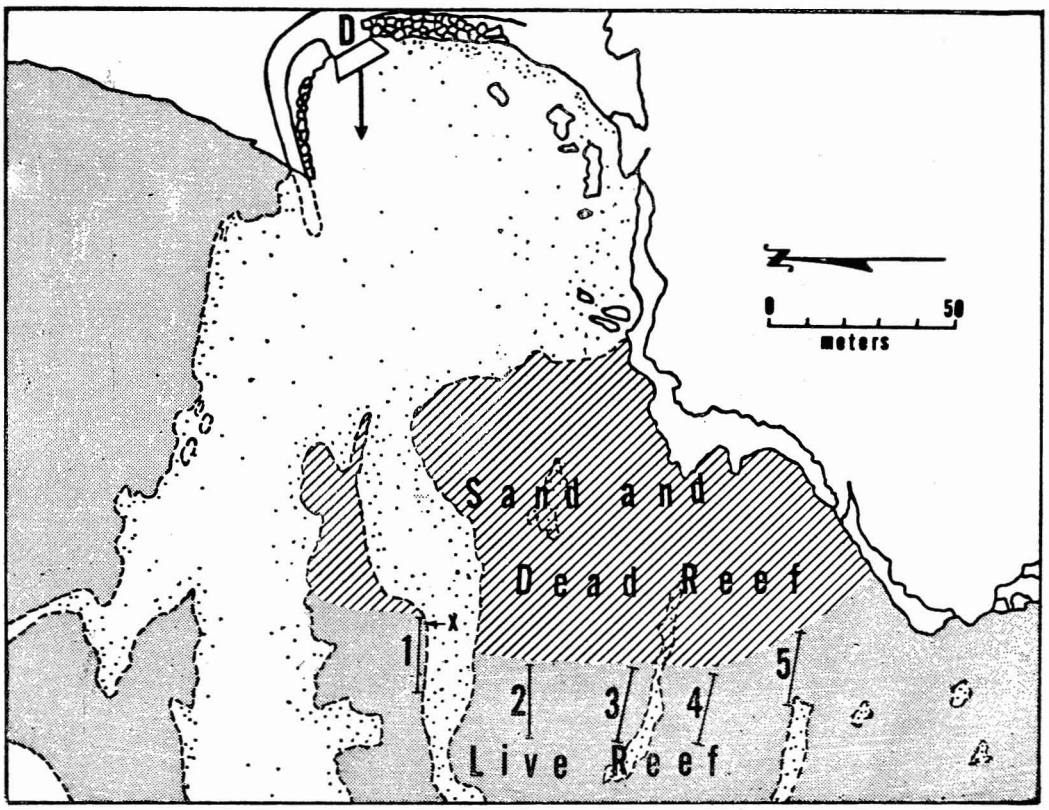

FIGURE 1. Map of Kahe discharge area showing locations of discharge structure (D), benthic temperature measurement (X), and transects 1–5.

Benthic temperatures were monitored at the shoreward ends of transects 1 and 6 between 9 August and 27 October, coinciding with the time of annual ambient temperature maxima. Because thermal effluent remains stratified at the water surface except when mixed by wave turbulence, the measurements made in the shallow water at the shore end of transect 1 represent estimates of maximum thermal influence by station effluent on live corals remaining in the discharge area. Benthic temperatures were measured for 1–5 day periods using Peabody-Ryan model F recording thermographs. Also, Taylor maximum-minimum thermometers were used at transect 1 from 26 July through 11 September for determinations of weekly temperature extremes.

RESULTS AND DISCUSSION

Thermograph recordings and weekly maximum temperature readings (Figure 2) indicate that bottom temperatures at transect 1 did not exceed 31.0° C through 11 September. Maximum temperature measured during the July–October period was 31.5° C, as shown by the 25–27 September thermograph recording. Unfortunately, no weekly maximum temperature values are available after 11 September, but good agreement was shown between previous maximum weekly temperatures and the shorter term thermograph recordings, suggesting that the thermograph maximum temperatures indicate antecedent conditions. Bottom temperatures at transect 6 were continuously stable at 26° C during three 24-hour recordings made between 23 August and 6 September.

The condition of the tagged *P. meandrina*

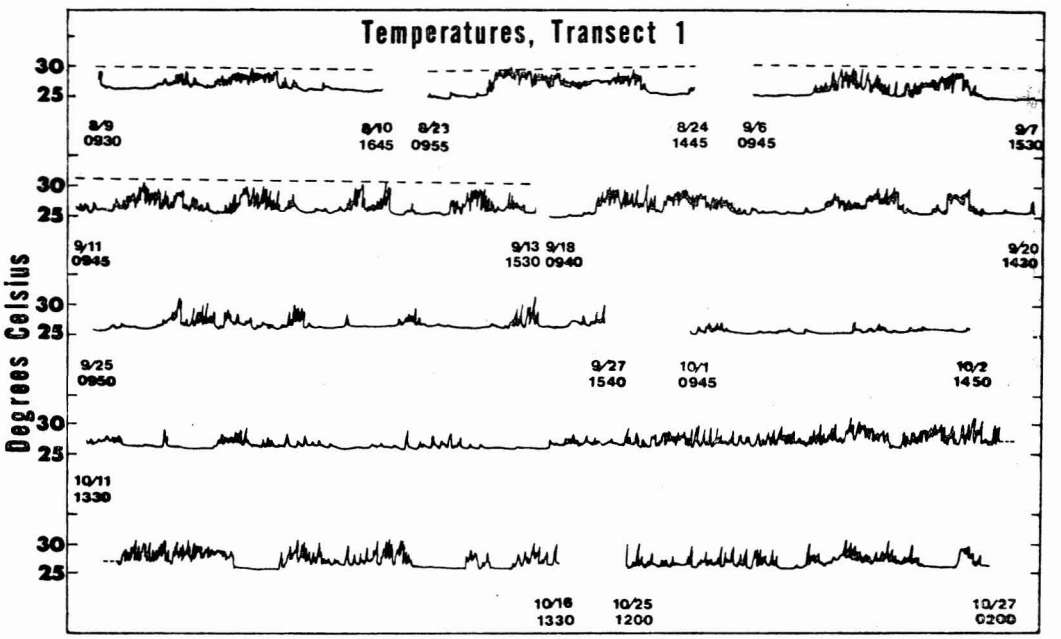

FIGURE 2. Bottom temperatures at transect 1 as measured by Peabody-Ryan model F recording thermograph (solid lines) and Taylor maximum-minimum thermometers (dotted lines, maximum temperature of previous week).

colonies on the six transects throughout the observation period is summarized in Figure 3. Although an increasing number of specimens on transects 1–5 showed some loss of zooxanthellar pigment through 1 October, thermal stress was insufficient to impart complete pigment loss (bleaching) to more than a few specimens, which occurred mainly on transect 2. Pigment loss decreased with distance from the discharge along these transects except on transect 5, where corals throughout the length of the transect showed approximately equivalent pigment reductions. By 14 December most colonies had recovered their original pigmentation, and no bleached colonies could be found on any transect. Of the total of 198 colonies originally tagged on transects 1–5, 14 (7 percent) died during the study. A similar percentage mortality (6.5 percent) occurred during August–December on transect 6, where no alterations of ambient bottom temperature or bleaching of specimens occurred.

On 30 October, the shoreward edge of the live coral zone in the discharge area was surveyed and the number of bleached *P. meandrina* heads counted. Ten colonies were found to be completely or mostly bleached, and 43 colonies were found in a partly bleached condition. By contrast, recent coral damage in 1971 was estimated by Jokiel and Coles (1974) to have occurred on 0.38 hectare (0.94 acre) of reef, increasing in 1972 to 0.71 hectare (1.76 acre). Moreover, more resistant species than *P. meandrina* were killed or damaged during those periods. Coral damage previous to the summer of 1973 apparently occurred to nearly its maximum extent, and water depth at the present living reef fringe is sufficient to prevent extensive thermal damage to most of the remaining live corals under present levels of discharge.

The temperatures encountered by corals on transects 1–5 continually varied 3°–4° C during every low tide. Despite a thermal environment where temperature fluctuations within minute periods sometimes approximated the normal annual temperature range of the open ocean in Hawaii (Jokiel and Coles 1974), coral damage on transects 1–5 was limited and coincided with the period of maximum water temperatures.

These results indicate that the upper absolute temperature encountered by a reef coral is a far more critical factor in producing damage and

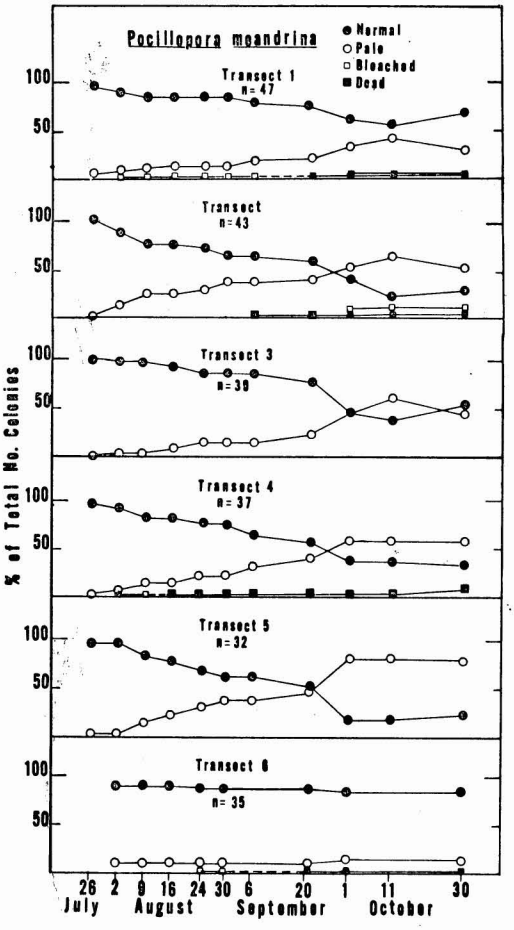

FIGURE 3. Condition of tagged *Pocillopora meandrina* colonies July–October 1973 on transects 1–6.

mortality than are rapid temperature fluctuations near upper thermal limits. Previous studies (Coles 1973; Jokiel and Coles 1974; Jokiel and Coles, unpublished) have demonstrated temperatures exceeding 31° C for substantial periods to induce rapid bleaching and mortality in *P. meandrina* and in other coral species in Hawaii. The present study indicates that, while temperatures in the study area often approached and sometimes exceeded 31° C, only sublethal effects were observed for most specimens, and specimens returned to normal when lower ambient temperatures occurred. Despite rapid temperature fluctuations of up to 4° C coinciding with wave mixing of thermal effluent with ambient water during every low tide, coral damage was not extensive. Short-term thermal shock may therefore be considered a minimal effect to corals exposed to high temperature stress.

LITERATURE CITED

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